Fig. 1.

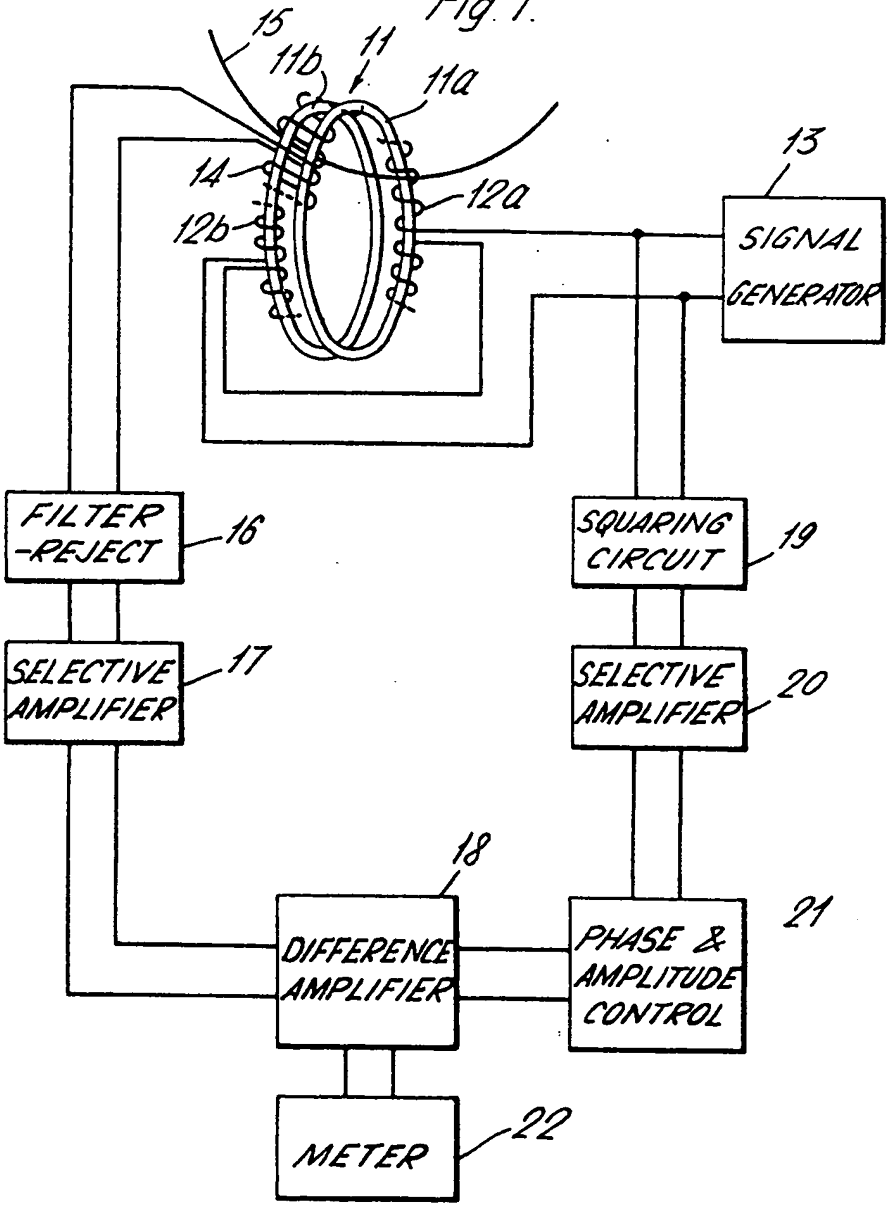

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Fig. 2a.

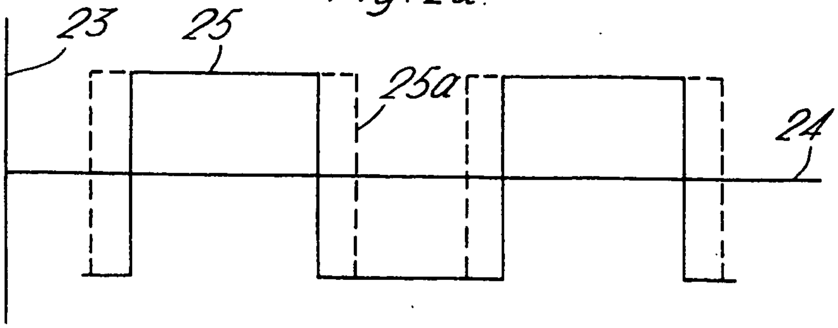


Fig. 2b.

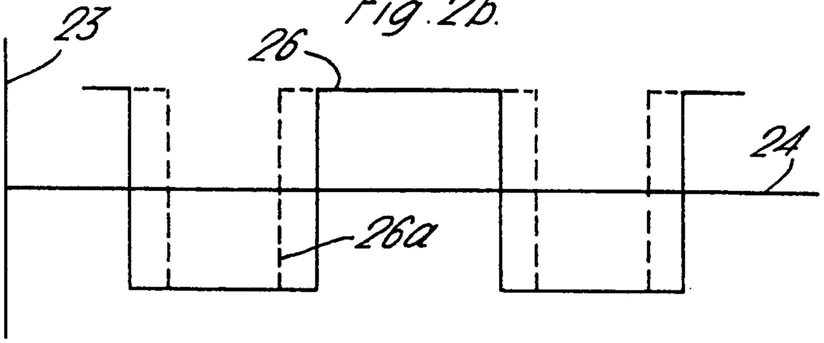
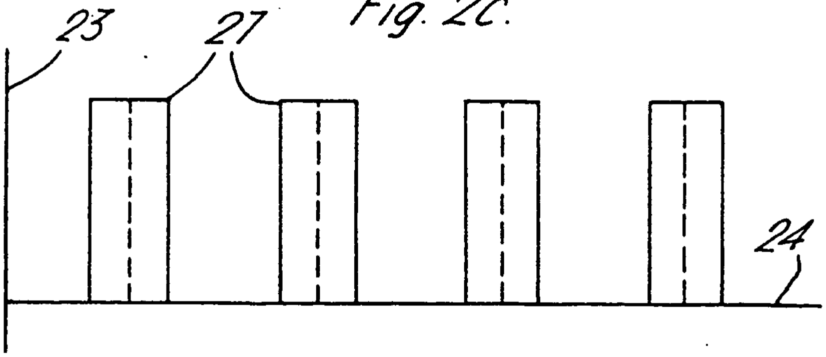


Fig. 2c.



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This invention relates to apparatus for measuring electrical current flowing in a conductor and particularly to such apparatus for measuring direct current without contacting the conductor.

In oil refineries cathodic protection is used to reduce corrosion in pipes carrying the oil products around the refinery. The cathodic protection involves the flow of direct current through the pipes. With the complex arrangement of pipes in a refinery it is impossible to calculate the amount of current flowing through a particular length of pipe. Normal measuring instruments which contact the pipes alter the characteristics of the system and so a true current value cannot be obtained.

When it is required to make a break in the pipe there may be a fire risk due to a spark on breaking the pipes which may contain highly inflammable fluids. Because there is no convenient method of measuring the current flow, extreme fire precautions have to be taken even though there may only be a very small current flowing which would not involve a fire risk.

It is an object of the present invention to provide apparatus for measuring electrical currents flowing in conductors of large cross-section without contacting the conductors.

According to the present invention we provide an apparatus for measuring electrical current flowing in a conductor without contacting the conductor comprising a magnetic transducer having a closed-loop magnetic circuit adapted to be placed around the conductor, the transducer having an input circuit adapted to saturate the magnetic circuit when an alternating current is fed thereto and an output circuit adapted to produce output signals substantially indicative of the value of an electrical current flowing through the conductor, and circuit means external to the transducer connected

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between the input and output circuits for balancing the input and output circuits in such manner that an accurate indication of the current flowing in the conductor can be obtained.

The transducer may be in the form of a plurality of magnetic cores placed in close proximity with one another forming the magnetic circuit, the input circuit comprising a separate winding wound round each core and said windings extending symmetrically around the whole periphery of each core, the windings being connected in series and arranged to produce opposing magnetic flux in the cores, and the output circuit comprising a winding wound round all the cores and extending symmetrically around the periphery of the cores.

Conveniently two cores may be used and may be positioned side by side with the closed-loop magnetic paths adjacent.

The external circuit means may include a selective circuit for selecting a signal from the output circuit, the signal being one which is produced by a current flowing in the conductor and being a harmonic of the alternating current supply frequency, and circuit means for producing a further signal from the alternating current supply having the same harmonic frequency as the said signal, the further signal being adjustable to balance the said signal produced, due to imperfections in the transducer when the current carrying conductor is not present, in such manner that the two signals can be compared to produce an indication of the value of current flowing in the conductor.

The external circuit means may also include a filter arranged between the output circuit of the transducer and the selective circuit and adapted to block the passage of alternating current having the same frequency as the alternating current supply.

In order that the invention may be more clearly understood a specific embodiment will hereinafter be described, by way of example only, with reference to the accompanying drawings, in which:-

Fig. 1 shows a block schematic representation of apparatus for measuring the current flowing in a conductor without contacting the conductor;

Figs. 2a, b and c show curves representative of the flux patterns produced in the windings of the transducer of Fig. 1.

Figure 1 shows a transducer 11 comprising two cores 11a and 11b carrying primary windings 12a and 12b respectively, connected in series to an alternating current signal generator 13. The two primary windings 12a and 12b which are substantially identical, are wound round the cores and extend symmetrically around the whole periphery of the cores (only part shown). The two primary windings 12a and 12b are either wound in opposite directions, or are connected, so that the cores 11a and 11b are magnetically saturated in opposite directions by the alternating current supply.

A secondary winding 14 is wound round both cores 11a and 11b and extends symmetrically around the whole periphery of the cores (only part shown).

With this arrangement, if the transducer were exactly balanced, the application of alternating current to the primary windings 12a and 12b would not cause any voltage to be induced in secondary winding 14. In this case a conductor 15 passing through the transducer 11 carrying a direct current would cause a voltage to be induced in the secondary winding 14, the value of which would be proportional to the value of the direct current. In practise it is not possible to make the two primary windings absolutely identical or to have all the windings exactly symmetrical on the cores.

It was found that by attempting to achieve a balance condition by additional windings or additional turns on the existing windings, the transducer was made more susceptible to effects from spurious magnetic fields outside the cores and was therefore less sensitive.

The best method of balancing the system was found to be by circuitry external to the transducer.

The secondary winding 14 is connected to a filter unit 16, which may be a so called "Twin - T" network, adapted to block signals having a frequency equal to the frequency of the supply from signal generator 13.

The filter unit 16 is connected to a selective amplifier unit 17 arranged to select a signal of a frequency which is a harmonic of the supply frequency, conveniently the second harmonic, and amplify it.

The selective amplifier unit 17 is connected to two inputs of a difference amplifier unit 18.

The output from the signal generator 13 (i.e. the input to primary windings 12a and 12b) is also fed to a squaring circuit 19, this circuit is required because the output from secondary winding 14 is in the form of a square wave as will be described in more detail hereinafter with reference to Fig. 2.

The squaring circuit 19 is connected to a selective amplifier 20 for selecting a signal of the same frequency as selective amplifier 17 i.e. a harmonic of the supply frequency, conveniently the second harmonic.

The selective amplifier unit 20 is connected via a phase and amplitude control unit 21 to the other two inputs of the difference amplifier 18.

The output of the difference amplifier 18 is connected to a meter 22 for indicating the value of current flowing in conductor 15.

The operation of the apparatus will now be described with reference to both figures. In Figs. 2a, b and c the vertical axes 23 represent flux values and the horizontal axes 24 represent time.

An alternating current signal is fed from signal generator 13 to the two series connected primary windings 12a and 12b. The core 11a is magnetically saturated in alternate positive and negative directions, the flux pattern being substantially as shown by curve 25 in Fig. 2a. For corresponding cycles the core 11b is magnetically saturated in alternate negative and positive directions, the corresponding flux pattern being substantially as shown by curve 26 in Fig. 2b. It can be seen from the two flux patterns that theoretically the fluxes cancel and no voltage will be induced in secondary winding 14.

In practise the windings cannot be identical and so the system is not balanced. A square wave voltage output is obtained from secondary winding 14 having the same frequency as the alternating current supply. This voltage output is eliminated by filter unit 16. Some second harmonic of the voltage output is also produced and this is selected and amplified by unit 17 and fed via amplifier 18 to the meter 22. Hence a current value is indicated on the meter 22 when no conductor 15 is present.

The system is balanced and the meter returned to the zero position by units 19, 20 and 21. The alternating current supply is squared by the squaring circuit 19 and the second harmonic selected and amplified in unit 20. The output from unit 20 is fed to unit 21 where the phase and amplitude of the signal are adjusted to supply a balancing signal to the difference amplifier 18 that balances the signal from unit 17, so causing the output from unit 18 to be zero and hence causing the meter to indicate zero current flow.

With the apparatus balanced as described above the presence of the conductor 15, through the transducer 11, carrying a direct current and therefore having a non-conservative magnetic field encircling it, causes the line integral of the resulting magnetic field in the transducer to have a finite value. The resultant flux patterns in the cores 11a and 11b respectively, are altered as shown by the curves 25a and 26a (Figs. 2a and b). Hence the resultant flux pattern for the transducer 11 is shown by curve 27 in Fig. 2c. The resultant flux in the transducer causes a substantially square wave voltage output to appear across the secondary winding 14 together with the out of balance signals. The output passes through filter unit 16, is selected and amplified by unit 17 and passed to difference amplifier 18. The signal due to the output voltage caused by the current carrying conductor appears at the output of unit 18 and is indicated by meter 22.

With the balanced arrangement described above it is possible to measure the value of currents flowing in a conductor passing through the transducer without magnetic interference from fields caused by other current carrying conductors near the transducer but not passing through it.

In the use of the apparatus the transducer cores may become magnetized so causing incorrect readings to be produced. The cores can be demagnetized by a 50% increase in the magnetizing current in the primary windings which is applied for a short time i.e. about ten seconds. In practise it is advisable to apply the demagnetizing current every time before taking a reading to ensure that the cores are demagnetized.

With present arrangement the transducer can be made large enough to encircle fluid carrying pipes. An experimental model of the apparatus was built with a transducer large enough to encircle a pipe of twelve inches diameter. In this apparatus the primary windings and secondary winding each comprised 2000 turns on toroidal cores of 14 inches diameter. The alternating current was 20 volts at a frequency of 2.5 kilocycles per second and a current of 30 milliamps was caused to flow in the primary windings. With this arrangement an output of 1 millivolt was obtained across the secondary winding for each amp of current flowing in the conductor 15.

It was found that by placing a ring shaped shield (not shown) of "μ-metal" around the transducer effects due to extraneous magnetic fields were reduced without sensible reduction of output signal due to the current carrying conductor.

With this arrangement currents in the range of 1 milliamp to 100 amps can be measured.

Although the present balancing arrangement has been described utilizing a specific transducer construction it should be realized that it is not limited to such use and can be used with other constructions of transducer.

Although the transducer 11 is shown as a continuous ring in practise it is provided in two halves which mate together to enable the transducer to be placed around a current carrying conductor. The above and other details of the transducer construction are described more fully in our copending Canadian patent application No. 888,029 filed October 31, 1963.

THE EMBODIMENTS OF THE INVENTION IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. Apparatus for measuring the value of a direct electric current flowing in a conductor without contacting the conductor which includes a magnetic transducer having a closed-loop magnetic circuit adapted to be placed around the conductor, an input circuit adapted to saturate said magnetic circuit by means of alternating current fed thereto from a suitable source and an output circuit adapted to produce output signals indicative of the value of the direct electric current flowing through the conductor in which error signal eliminating means external to said transducer are provided for cancelling out any error output signal which may be produced by said transducer when said conductor is not present in said transducer, said error signal eliminating means comprising apparatus for deriving from the alternating current source feeding said input circuit a balancing signal of the same form and amplitude as said error output signal and circuit means for combining the output signal from said transducer with said balancing signal in a subtractive sense whereby the resultant signal from said combining means is representative only of the current flowing in said conductor.

2. Apparatus according to claim 1 in which said transducer has the form of a pair of substantially similar closed-loop magnetic cores located in close proximity and in side-by-side relationship to one another to form said magnetic circuit, said input circuit comprising a separate input winding wound toroidally around each core with each winding extending symmetrically around the whole of the periphery of the core, said windings being connected in series and arranged to produce magnetic flux in mutually opposed directions

in the respective cores and said output circuit comprising a winding which is wound around both of the cores and their respective input windings and which extends symmetrically around the whole of the periphery of such wound cores.

3. Apparatus according to claim 1 in which said output circuit includes a frequency selective circuit for selecting a signal which is harmonic of the frequency of said alternating current source and in which said error signal eliminating means comprise means for producing from said alternating current source a signal having the same harmonic frequency as said selected signal, further circuit means for varying the phase and amplitude of said produced harmonic frequency signal to form said balancing signal and a differential amplifier which is arranged to be supplied at one input with said selected signal and at its other input with said balancing signal.

4. Apparatus according to claim 2 in which the selected signal is the second harmonic of the alternating current source frequency.

5. Apparatus according to claim 3 or 4 in which the selected signal is the second harmonic of the alternating current source frequency.

6. Apparatus according to claim 3 or 4 which includes a filter connected in series between the output circuit of the transducer and said frequency selective circuit, said filter being arranged to block the passage of alternating current having the frequency of said alternating current source.

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